

TECHNICAL NOTE

D-1311

EXPERIMENTAL DAMPING OF LIQUID OSCILLATIONS IN
A SPHERICAL TANK BY POSITIVE-EXPULSION BAGS
AND DIAPHRAGMS

By Andrew J. Stofan and Albert J. Pavli

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SUMMARY

A preliminary investigation was conducted to evaluate the slosh-damping effectiveness of positive-expulsion bags and diaphragms in a 9.5-inch-diameter spherical tank. The bags were installed with the liquid outside and the ullage inside. The maximum slosh forces that occurred at the first natural mode were approximately 50 to 60 percent lower than the forces with the unrestricted liquid. The bags and diaphragms eliminated a lower force peak at the second natural mode. Damping ratios (or logarithmic decrements) as high as 0.28 were measured, and liquid swirl, which was observed at the natural modes for the unrestricted liquid, was completely suppressed.

INTRODUCTION

For space vehicles and booster stages containing relatively large masses of liquid propellants, sloshing is a potential critical disturbance to the stability of the vehicle because it can produce forces and moments and can shift the center of gravity of the vehicle. It is of interest, therefore, to damp or eliminate sloshing in the propellant tanks. Investigations have been conducted to study liquid slosh characteristics and to evaluate methods of damping the liquid oscillations in tanks of various configurations and size (i.e., refs. 1 to 7).

Spherical tanks are being considered for numerous space-vehicle applications because of the advantage of minimum tank weight for a given volume. Experimentally verified methods for analytically predicting both the fundamental frequencies and the forces of unrestricted liquid oscillations in spherical tanks are reported in reference 8. In some applications elastomer positive-expulsion bags or diaphragms may be used for propellant transfer under weightless conditions. Therefore, it is of interest to define the damping effectiveness of such positive-expulsion devices.

A preliminary experimental investigation was conducted at the NASA Lewis Research Center to study slosh-damping effectiveness of positive-expulsion bags and diaphragms. Bags and diaphragms of butyl rubber, varying in thickness from 0.010 to 0.020 inch, were tested in a 9.5-inch-diameter spherical tank to measure the slosh forces and damping characteristics over a range of exciting frequencies extending through the first two natural modes of the contained liquid. The results of this investigation are presented herein.

SYMBOLS

- d spherical diameter, in.
- F_s slosh force, lb
- g gravitational acceleration, 386 in./sec²
- h liquid depth, in.
- R spherical radius, in.
- X_0 excitation amplitude, in.
- α circular frequency, radians/sec
- δ damping ratio, $\ln (F_{s,n}/F_{s,n+1})$
- ρ density, slugs
- Subscript:
- n (1,2,3,4,..., n)

APPARATUS AND INSTRUMENTATION

The experimental test facility, shown in figure 1, was also used in the investigation of unrestricted liquid sloshing reported in reference 8. A 9.5-inch-diameter spherical tank was formed in a lucite block. The block was mounted on ball bearings and was free to oscillate in a horizontal plane. The oscillatory motion of the block was provided by a driving mechanism powered by an electric motor. The driving amplitude could be varied from 0 to 0.100 inch and the frequency from 0 to 5 cycles per second. The electric motor was wired so that alternating current could be removed from the field and direct current applied to one of the windings. The oscillatory motion could then be "quick-stopped" so that residual horizontal forces resulting from the sloshing liquid

could be sensed by a strain gage mounted between the lucite block and the driving mechanism. The signal from the strain gage was recorded by a recording oscillograph.

In the experimental phase of reference 8, mercury and water were used as test liquids; nondimensional frequency and force parameters made the results independent of the liquid density. For the present investigation, mercury was selected for the bag and diaphragm tests in order to obtain larger slosh forces with a small excitation amplitude and thus increase the accuracy of the data.

The butyl rubber expulsion bag and diaphragm and the installation of these devices in the spherical tank are shown in figures 2 and 3, respectively. The bags and diaphragms were installed so that there was no air between the expulsion device and the contained liquid. The bags were 0.015 and 0.020 inch thick, and the diaphragms were 0.010, 0.015, and 0.020 inch thick.

PROCEDURE

For each bag and diaphragm, the block was oscillated at a preselected frequency and amplitude and quick-stopped, and the residual horizontal slosh forces were recorded. The frequency was varied from zero through the first two natural modes of the contained liquid. Each configuration was tested at amplitudes X_0 of 0.050 and 0.100 inch. Most of the tests were run at a liquid-depth ratio (liquid depth/tank diameter) of 0.50 in order to obtain maximum slosh forces for a given excitation amplitude (ref. 8); however, check runs were also made at a liquid-depth ratio of 0.25.

DATA REDUCTION

The experimentally obtained values of slosh force and frequency were reduced to dimensionless parameters $F_s/\rho g d^3 (X_0/d)$ and $\alpha\sqrt{R/g}$ as described in reference 1. The g term appearing in these parameters is equal to the vertical acceleration on the tank (386 in./sec² for the present investigation). The slosh forces are presented in this manner mainly for convenience, since the generalization and absence of scale effects have not been established for operation with positive-expulsion bags or diaphragms. The independent variable, the oscillatory frequency parameter $\alpha\sqrt{R/g}$, was varied over the range 0 to 2.4, which included the natural frequencies of the first two modes for all configurations tested. The damping ratio was determined by averaging several successive values of $\ln (F_{s,n}/F_{s,n+1})$ for each run, $F_{s,n}$ being the peak force on one slosh cycle and $F_{s,n+1}$ the peak force on the succeeding cycle. Typical force-time traces for both unrestricted liquid sloshing and sloshing with a bag or diaphragm installed in the tank are shown in figure 4. The force parameters were calculated from the magnitude of the first force peak observed after the quick stop. The damping ratios were

calculated as the logarithmic decrement of a smooth curve faired through successive force peaks.

This method of data reduction yielded accuracies of approximately ± 6 percent in the slosh-force parameter and approximately ± 15 percent in the damping ratio.

RESULTS AND DISCUSSION

Liquid-Depth Ratio of 0.50

Slosh forces and the effectiveness of slosh-suppression methods are most important to missile design at conditions where the forces are at a maximum. From the investigation of unrestricted liquid slosh characteristics in a spherical tank reported in reference 8, it was observed that maximum slosh forces occurred at a liquid-depth ratio of 0.50 and at the first natural mode frequency. The forces due to unrestricted liquid sloshing decayed very slowly after the excitation was stopped.

The influence of the expulsion bag and diaphragm configurations on slosh forces at a liquid-depth ratio of 0.50 is shown in figure 5. The force parameter is presented as a function of the oscillatory frequency parameter for the bag (fig. 5(a)) and the diaphragm (fig. 5(b)) and compared with the experimental and analytical results for unrestricted liquid sloshing from reference 8. The maximum slosh forces with the bag and diaphragm configurations occurred at the first natural mode frequency and were approximately 50 to 60 percent lower than the forces with the unrestricted liquid. A secondary force peak observed with unrestricted liquid at the second natural mode frequency was eliminated by the bag and diaphragm configurations. Within the range of variables examined, slosh-suppression effectiveness of the bag and diaphragm configurations was essentially similar and seemed to have been affected only by the thickness of the bag or diaphragm. As the material thickness was increased, the maximum slosh forces tended to decrease, and the first natural mode frequency tended to increase.

The influence of the expulsion bag and diaphragm configurations on the rate of decay of slosh forces at $h/2R$ of 0.50 is presented in figure 6 in terms of damping ratio (logarithmic decrement) as a function of the oscillatory frequency parameter. As the thickness of the bag or diaphragm material was increased, damping ratio (rate of decay of the forces) increased. Essentially comparable damping ratios were provided by the bag and diaphragm configurations, the maximum being about 0.28 with either a bag or a diaphragm.

A phenomenon that is frequently encountered in liquid sloshing is a rotational slosh mode referred to as liquid swirl. At least one missile failure has been attributed to such a disturbance. Liquid swirl occurs most often as a degeneration of linear or conventional sloshing at frequencies near or equal to the natural mode frequencies. Although

frequently encountered with unrestricted liquid, the liquid swirl phenomenon was completely absent with the bag or diaphragm configurations installed.

The effect of excitation amplitude X_0 on the slosh-force parameter and damping ratio is shown in figures 7 and 8. Force parameter and damping ratio are presented as functions of the oscillatory frequency parameter for two diaphragm configurations at excitation amplitudes of 0.050 and 0.100 inch, the latter amplitude being the maximum available. Within the range investigated and within the accuracy of the data, the excitation amplitude had no significant effect on the level of the slosh-force parameter or damping ratio and only a slight effect on the first natural mode frequency.

Liquid-Depth Ratio of 0.25

The influence of expulsion-bag or diaphragm configurations on slosh forces was briefly investigated at a liquid-depth ratio $h/2R$ of 0.25. These results are presented in figure 9 in terms of the slosh-force parameter as a function of the oscillatory frequency parameter and compared with experimental results for unrestricted liquid sloshing.

As expected, use of the bag or diaphragm configurations significantly lowered the maximum slosh forces near the first natural mode frequency. As with the 0.50 depth ratio, there were no secondary force peaks at the second natural mode frequency. Liquid swirl was also absent, as it was with a depth ratio of 0.50. Damping ratios are not presented for this depth ratio because the low slosh-force levels precluded accurate determination.

CONCLUDING REMARKS

A preliminary experimental investigation was conducted to study the slosh-damping effectiveness of positive-expulsion bags and diaphragms. Slosh forces and damping ratios were determined over a range of exciting frequencies for bags and diaphragms varying in thickness from 0.010 to 0.020 inch.

The maximum slosh forces with the bag and diaphragm configurations occurred at the first natural mode frequency and were approximately 50 to 60 percent lower than the forces with the unrestricted liquid. For the configurations investigated, there was a trend for the maximum slosh forces to decrease and the first natural mode frequency to increase as the thickness of the expulsion-device material was increased. The bag and diaphragm configurations eliminated the slosh-force peak observed with unrestricted liquid at the second natural mode frequency and completely suppressed liquid swirl. Damping ratios increased as the

thickness of the bags and diaphragms was increased; the maximum damping ratio was about 0.28 with either bags or diaphragms.

Lewis Research Center
National Aeronautics and Space Administration
Cleveland, Ohio, March 7, 1962

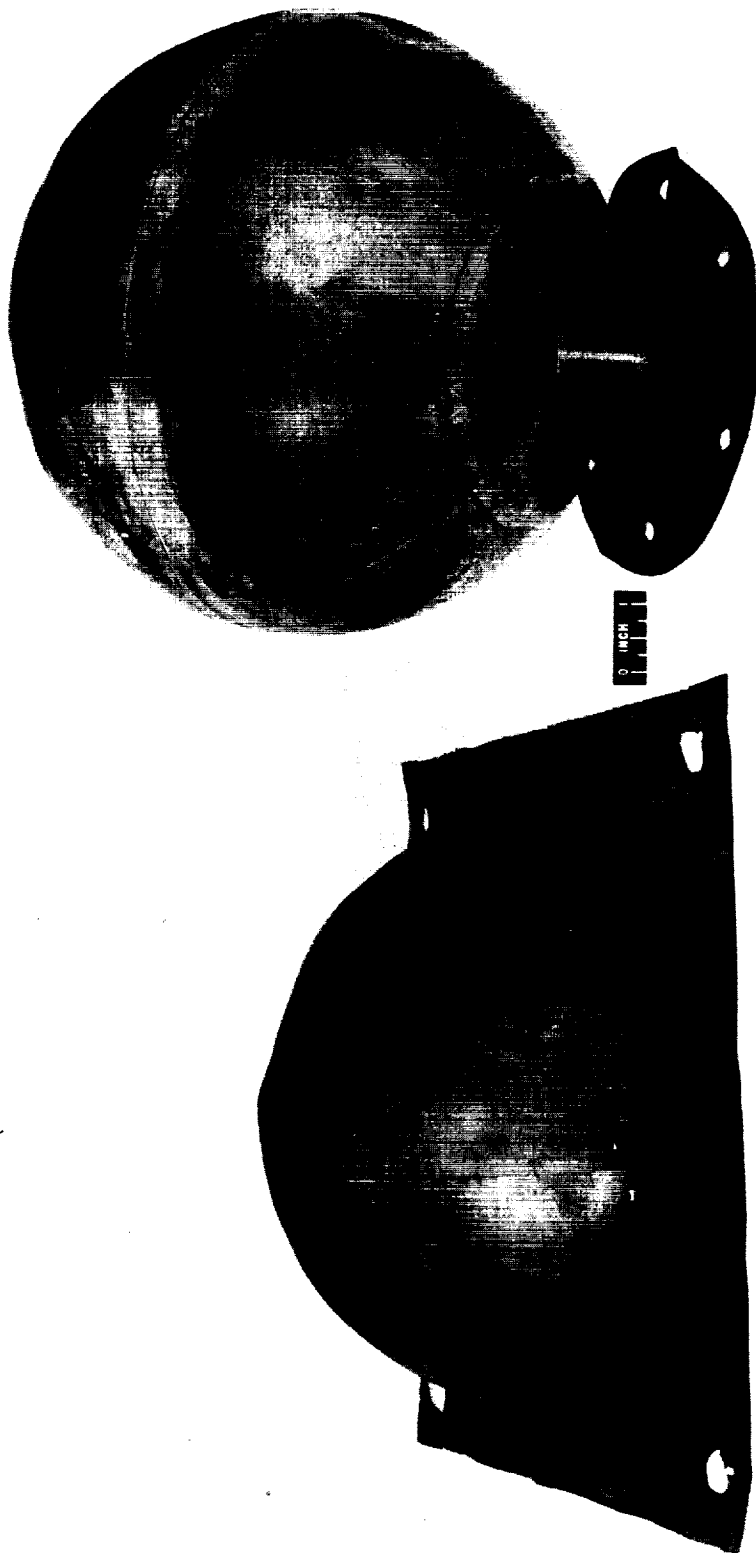
REFERENCES

1. Abramson, H. Norman, and Ransleben, Guido E., Jr.: Simulation of Fuel Sloshing Characteristics in Missile Tanks by Use of Small Models. Tech. Rep. 7, Southwest Res. Inst., Apr. 25, 1960.
2. Abramson, H. Norman, and Ransleben, Guido E., Jr.: A Note on the Effectiveness of Two Types of SLOSH Suppression Devices. Tech. Rep. 6, Southwest Res. Inst., June 15, 1959.
3. Bauer, Helmut, F.: Fluid Oscillation in a Cylindrical Tank with Damping. Rep. DA-TR-4-58, Army Ballistic Missile Agency, Apr. 23, 1958.
4. Bauer, Helmut, F.: Propellant Sloshing. Rep. DA-TR-18-58, Army Ballistic Missile Agency, Nov. 5, 1958.
5. O'Neill, J. P.: An Experimental Investigation of Sloshing. STL-TR-59-0000-09960, Space Tech. Labs., Inc., Mar. 4, 1960.
6. Stephens, David G., Leonard, H. Wayne, and Silveria, Milton A.: An Experimental Investigation of the Damping of Liquid Oscillations in an Oblate Spheroidal Tank With and Without Baffles. NASA TN D-808, 1961.
7. Cole, Henry A., Jr., and Gambucci, Bruno J.: Tests of an Asymmetrical Baffle for Fuel-Sloshing Suppression. NASA TN D-1036, 1961.
8. Stofan, Andrew J., and Armstead, Alfred L.: Analytical and Experimental Investigation of Forces and Frequencies Resulting from Liquid Sloshing in a Spherical Tank. NASA TN D-1281, 1962.



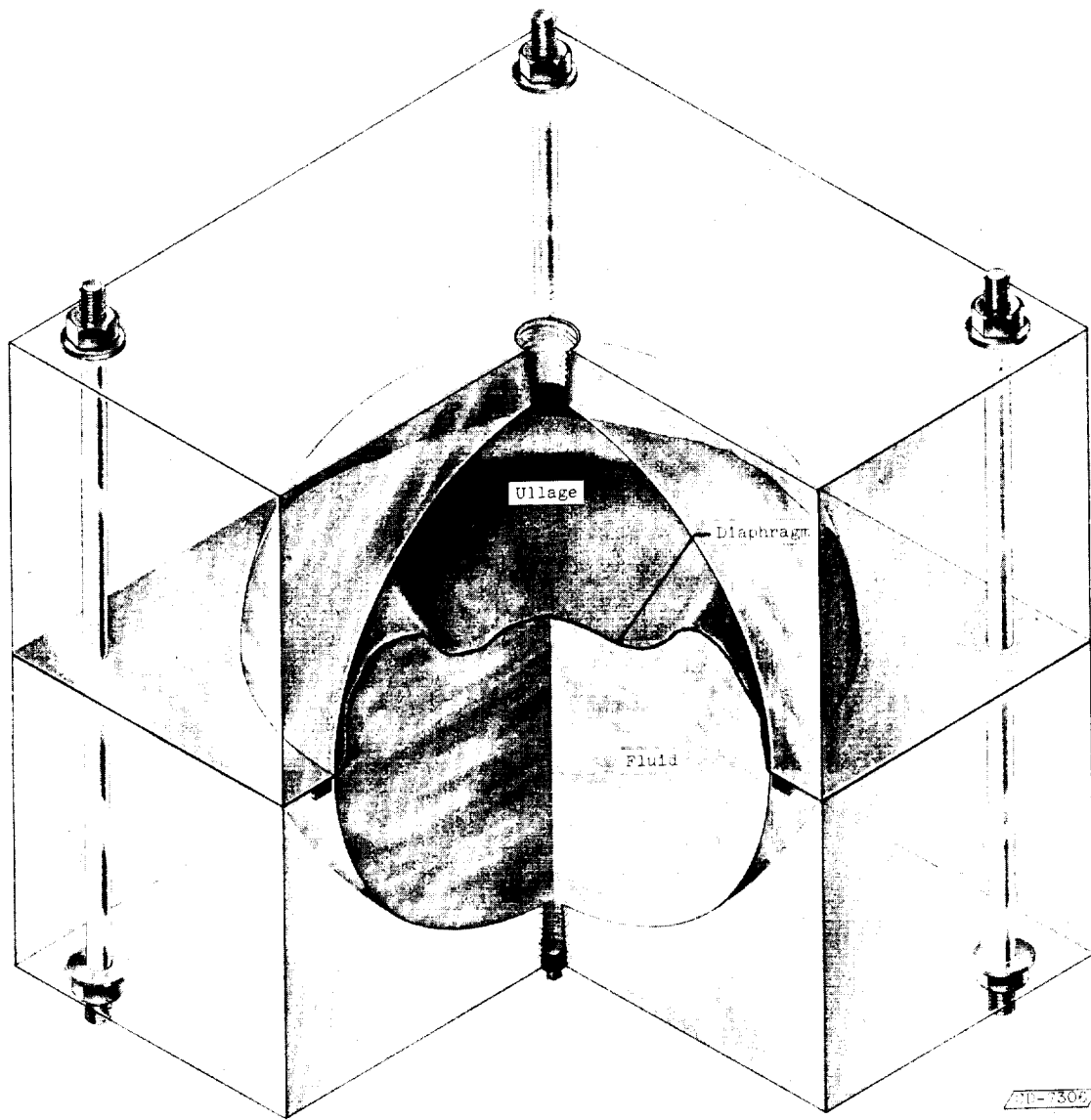
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Figure 1. - Experimental test facility.



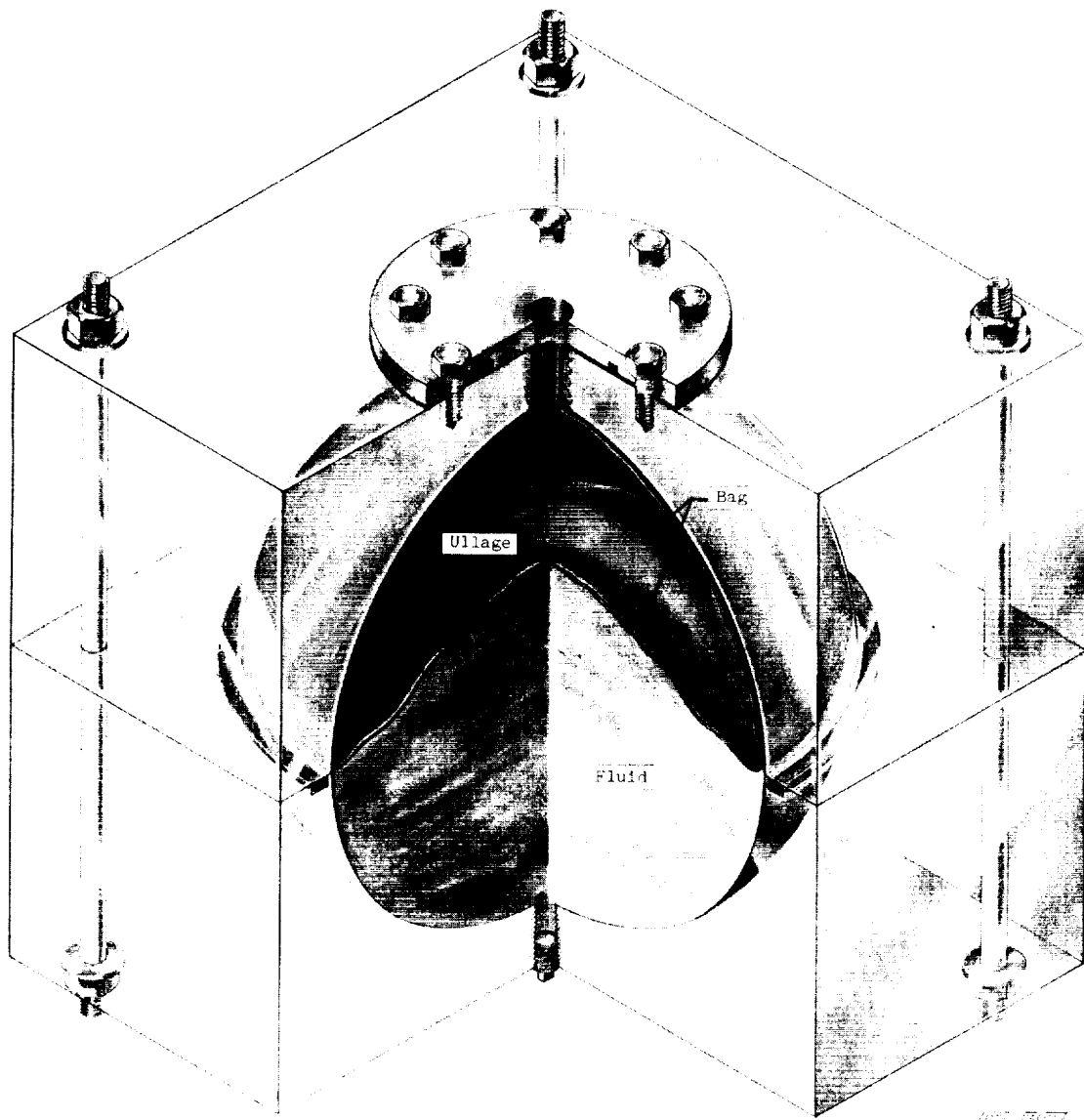
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Figure 2. - Positive-expulsion diaphragm and bag.



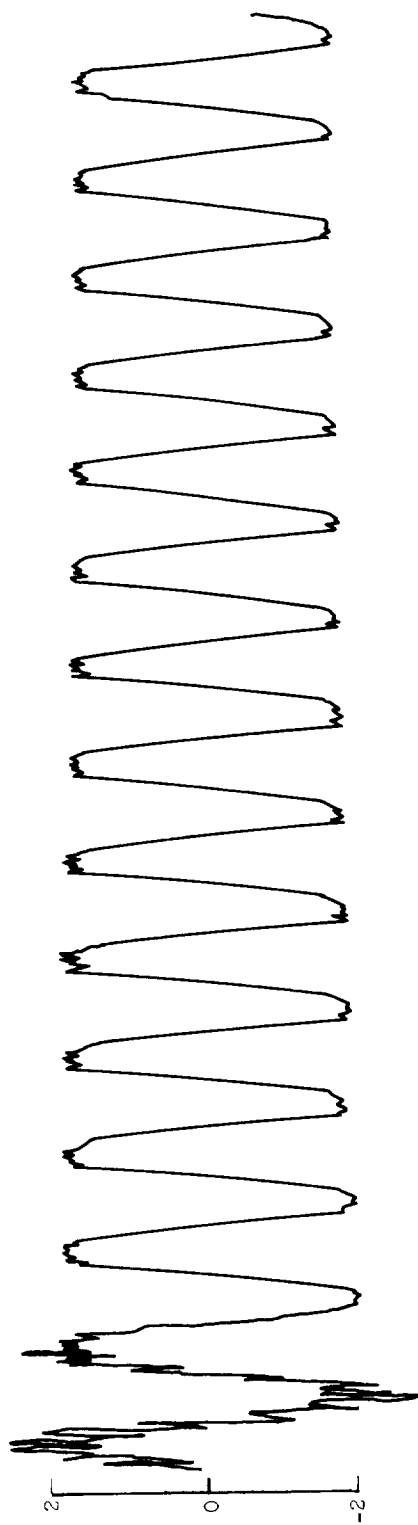
(a) Diaphragm.

Figure 3. - Diaphragm and bag installations in spherical tank.

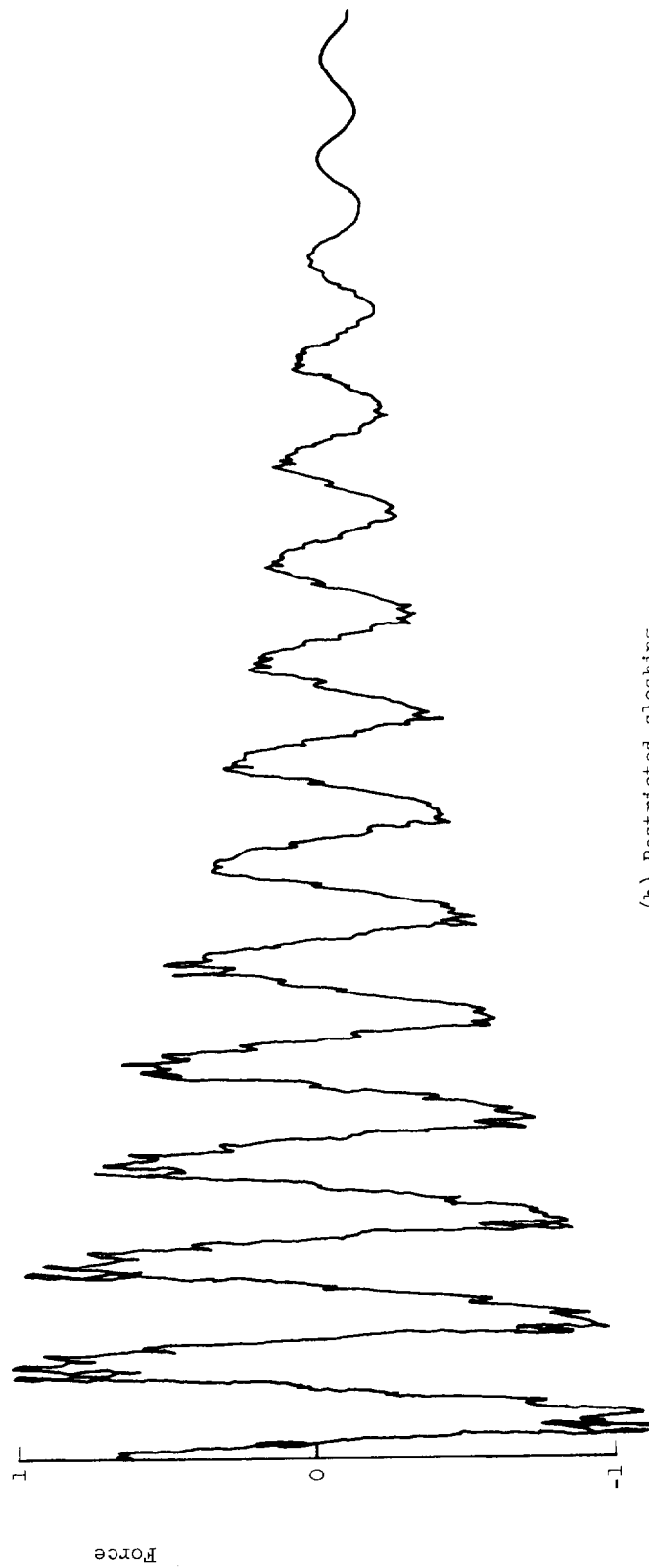


(b) Bag.

Figure 3. - Concluded. Diaphragm and bag installations in spherical tank.

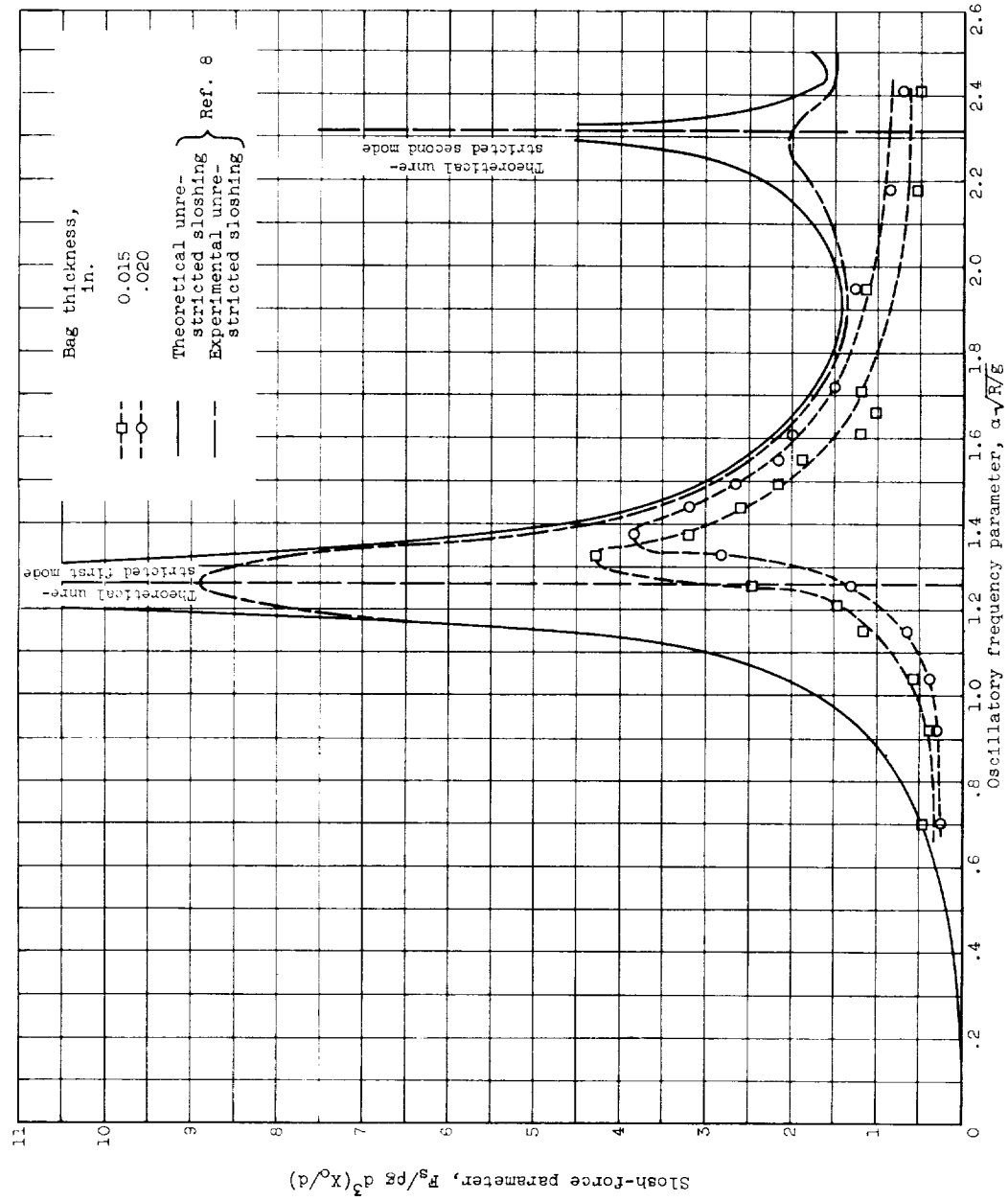


(a) Unrestricted sloshing.



(b) Restricted sloshing.

Figure 4. - Typical slosh-force traces. Liquid-depth ratio $h/2R$, 0.50; excitation amplitude X_0 , 0.05 inch.



(a) Bags.

Figure 5. - Effect of expulsion devices on slosh-force parameter. Liquid-depth ratio $h/2R$, 0.50; excitation amplitude X_0 , 0.05 inch.

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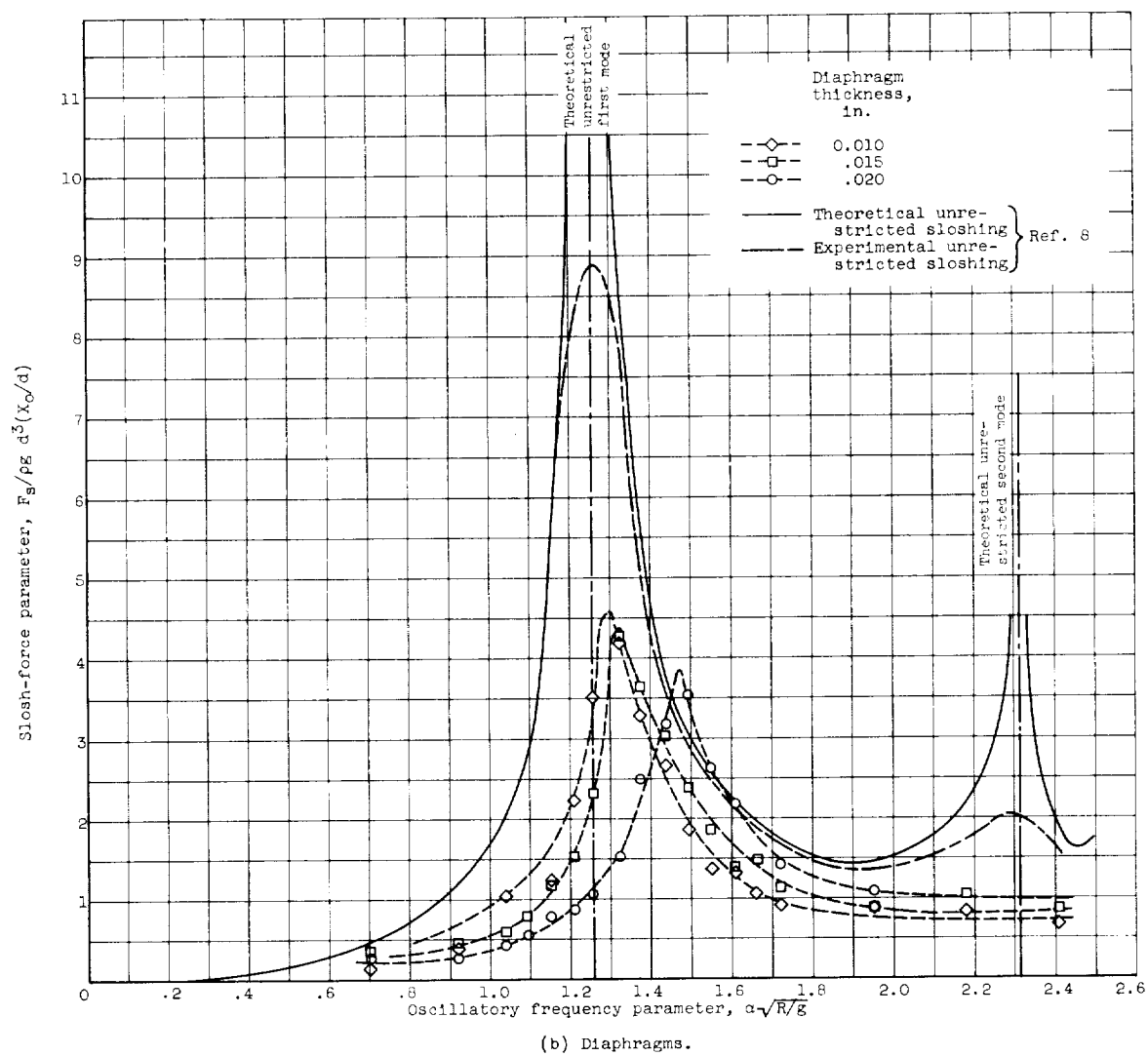


Figure 5. - Concluded. Effect of expulsion devices on slosh-force parameter. Liquid-depth ratio $h/2R$, 0.50; excitation amplitude X_0 , 0.05 inch.

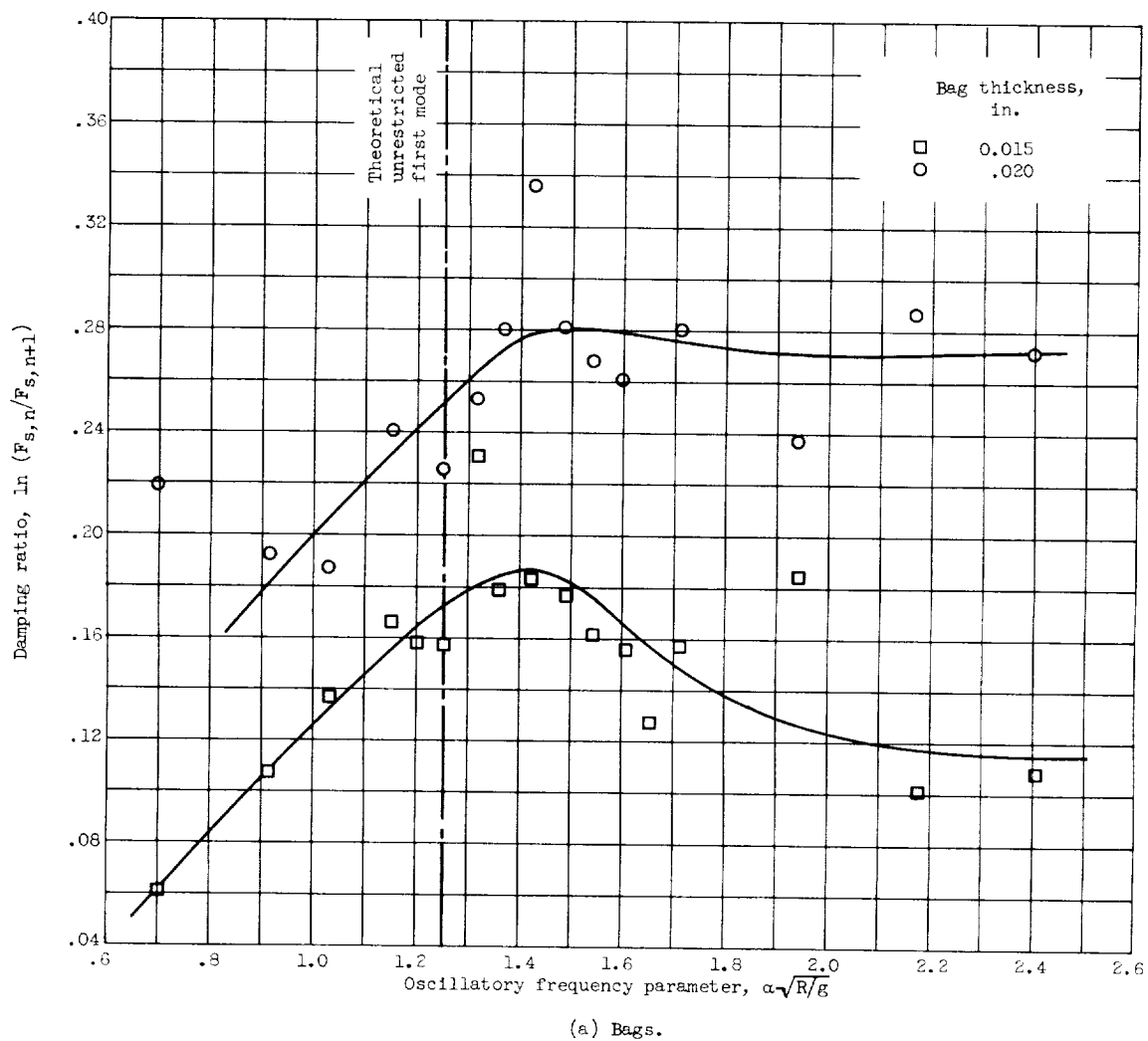
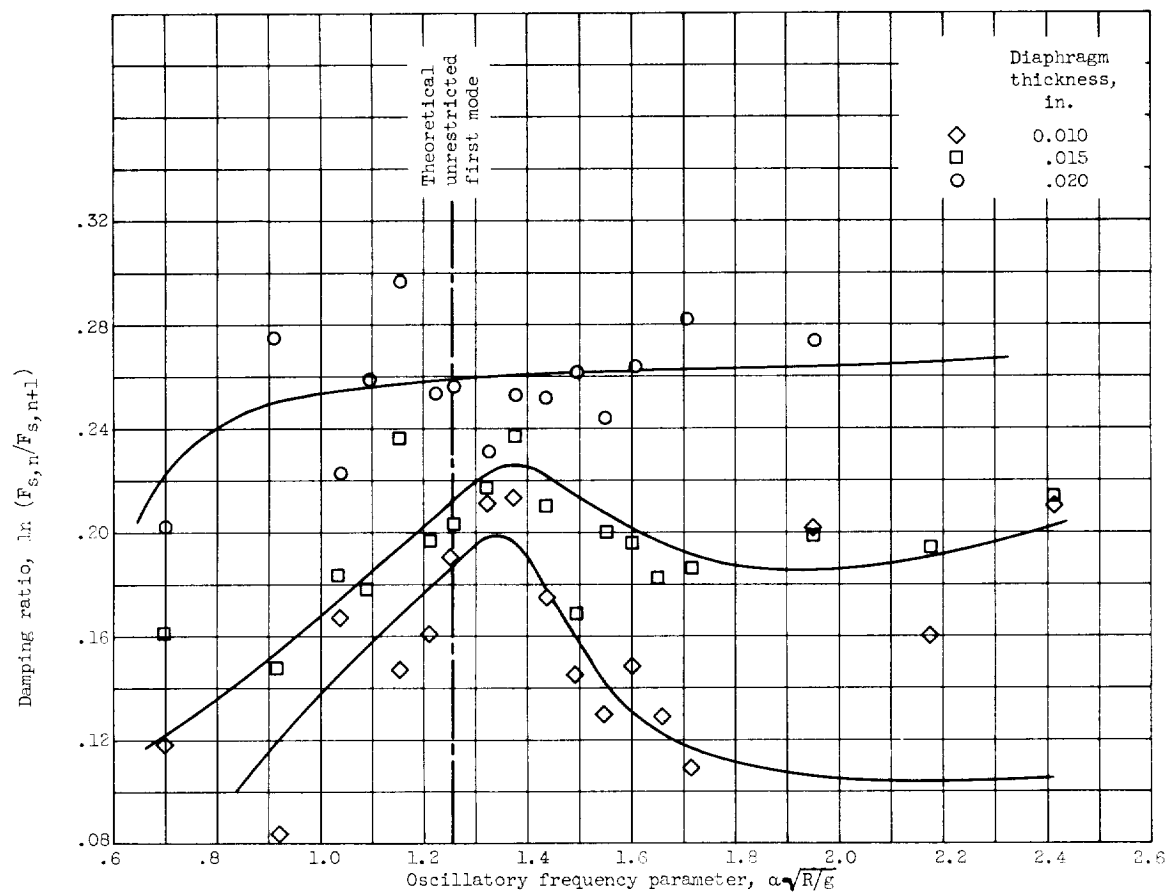


Figure 6. - Effect of expulsion devices on damping ratio. Liquid-depth ratio $h/2R$, 0.50; excitation amplitude X_0 , 0.05 inch.



(b) Diaphragms.

Figure 6. - Concluded. Effect of expulsion devices on damping ratio. Liquid-depth ratio $h/2R$, 0.50; excitation amplitude X_0 , 0.05 inch.

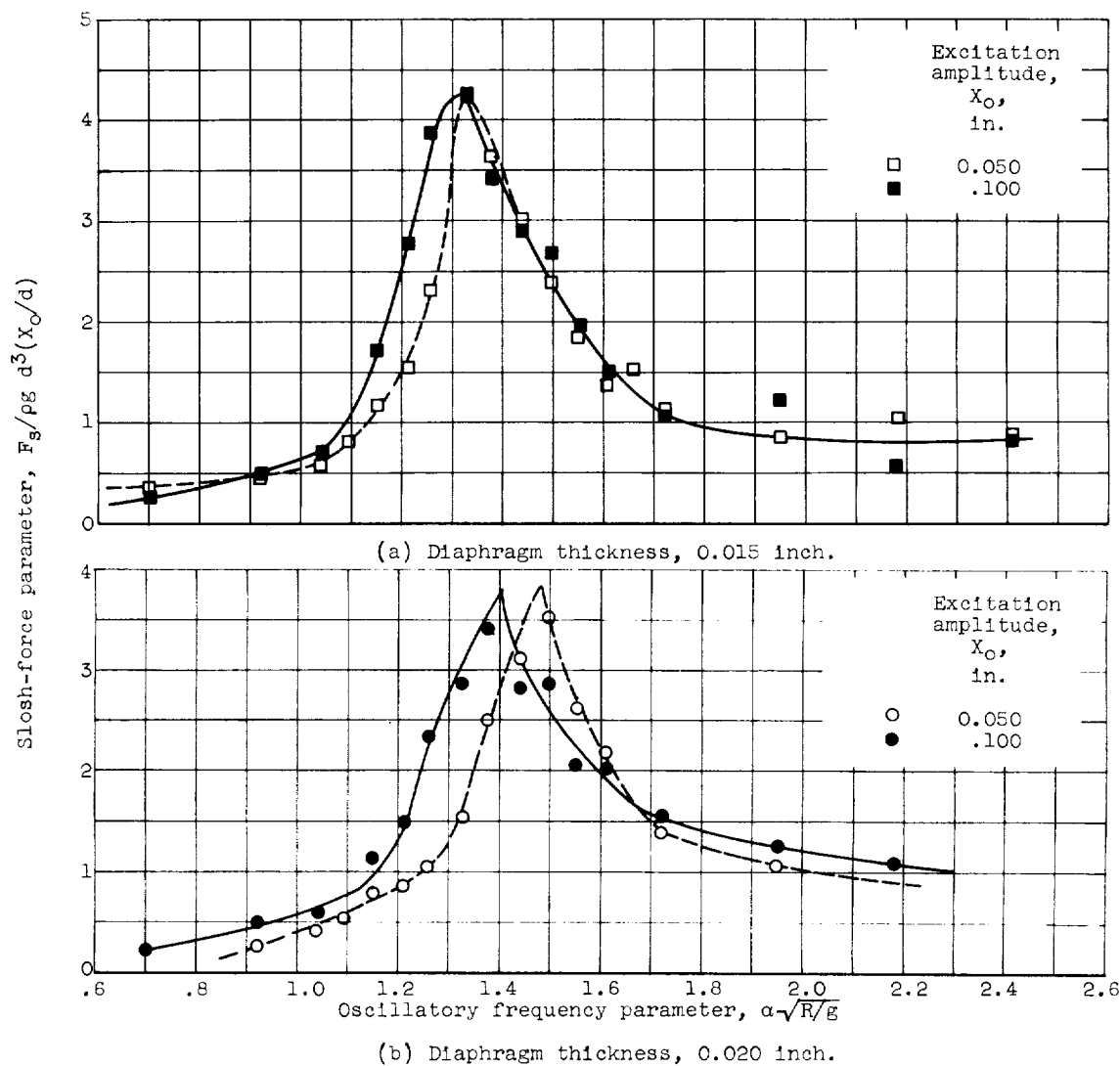
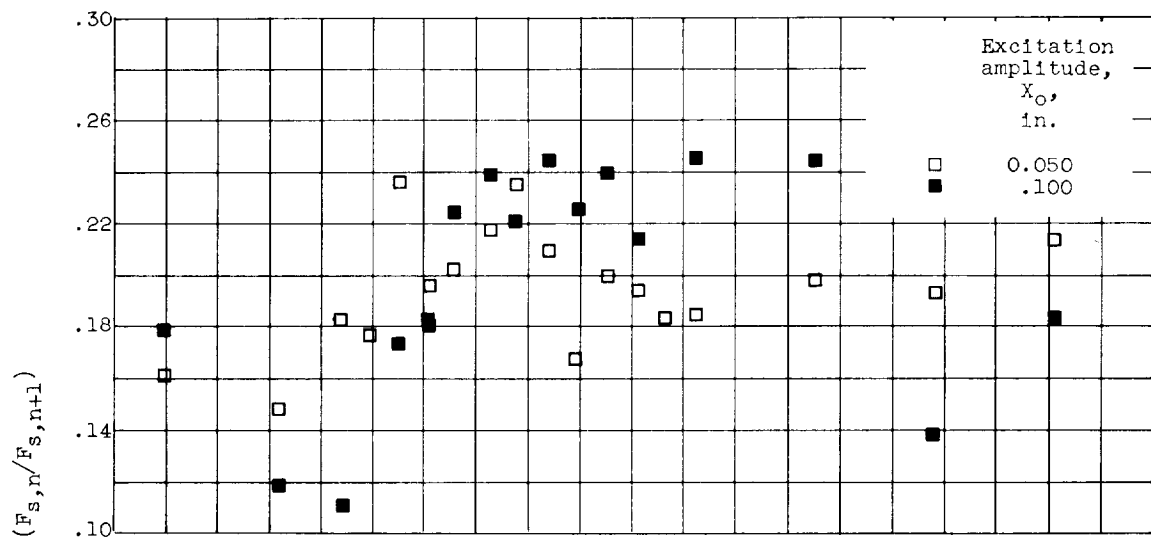
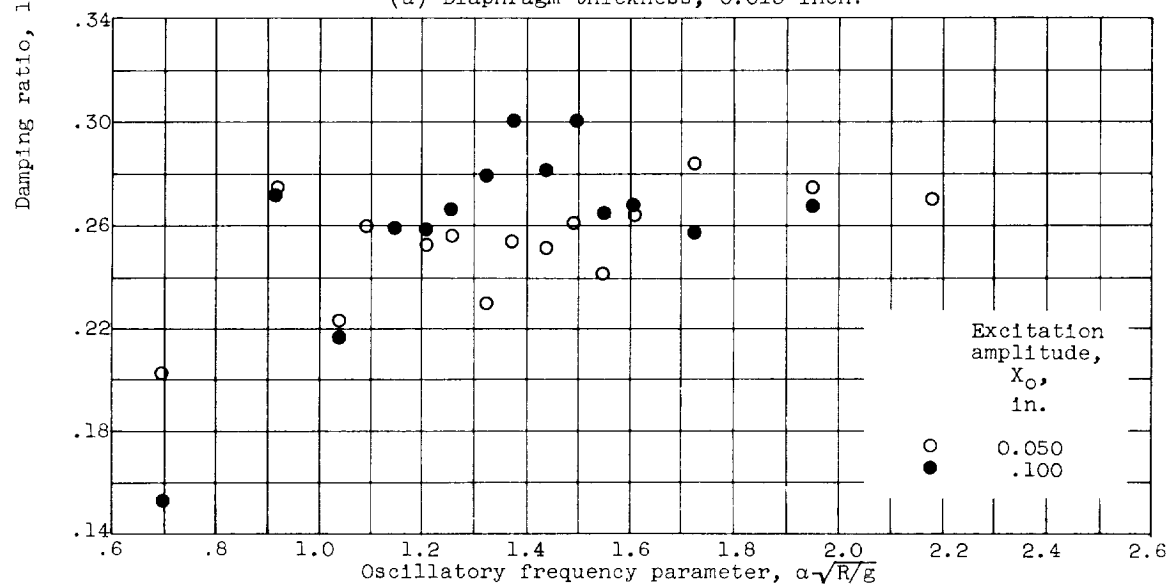


Figure 7. - Effect of excitation amplitude on slosh-force parameter. Liquid-depth ratio $h/2R$, 0.50.

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(a) Diaphragm thickness, 0.015 inch.



(b) Diaphragm thickness, 0.020 inch.

Figure 8. - Effect of excitation amplitude on damping ratio.

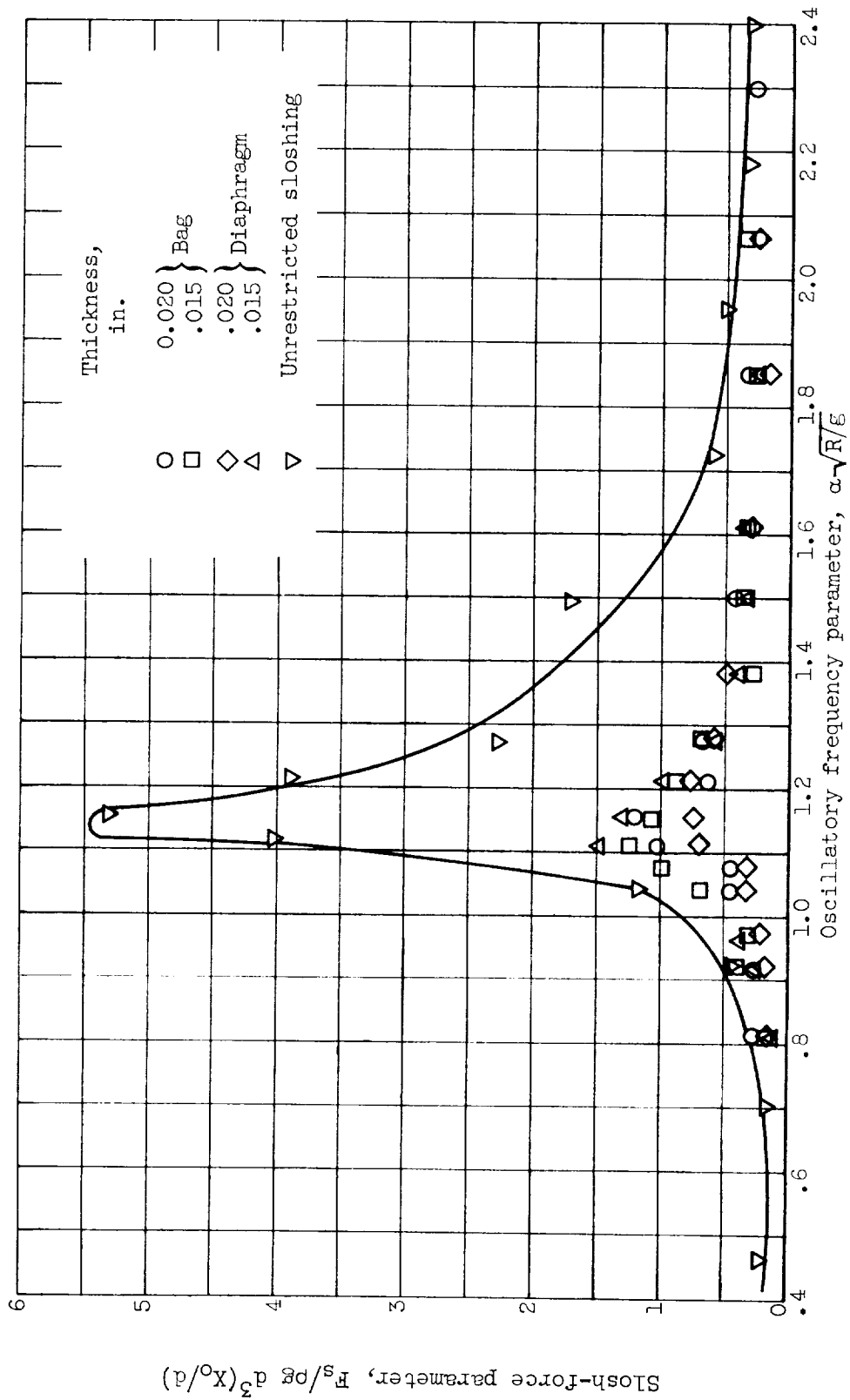


Figure 9. - Effect of expulsion devices on slosh-force parameter. Liquid-depth ratio $h/2R$, 0.25; excitation amplitude X_0 , 0.05 inch.

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- I. Stofan, Andrew J.
- II. Pavli, Albert J.
- III. NASA TN D-1311

(Initial NASA distribution:
20, Fluid mechanics;
24, Launching dynamics;
36, Propellants; 37, Propulsion system elements;
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